NASA's Radioisotope Power Systems Program: Status Update

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Radioisotope power systems (RPS) have safely been in use in the United States for over 60 years. RPS-enabled NASA missions have utilized space nuclear power to explore planets, moons, and interstellar space. This exploration resulted in changes to our understanding of our Solar System and our place within it. In 2010, NASA HQ established a NASA program to invest in RPS technologies and systems that could enable future missions. The RPS Program ensures the availability of RPS for the exploration of the solar system in environments where conventional solar or chemical power generation is impractical or impossible. The RPS Program, in partnership with the Department of Energy (DOE) Office of Nuclear Energy continues to operate as an interagency partnership to provide robust power system solutions to spacecrafts that conduct missions for exploration and science that otherwise would not be feasible. This paper provides a synopsis of current activities after well over a decade of formal interagency partnering.

I. PROGRAM CONTENT AND STRUCTURE

The RPS Program is responsible for acquisition and development of thermal energy conversion technologies and related system technologies, acquisition, and development of flight RPS designs for future mission use, as well as the management of National Environmental Policy Act (NEPA) and nuclear launch authorization activities related to RPS missions and systems. Additionally, the RPS Program maintains the capability to acquire future RPS through strategic investment in unique competencies that may be needed by future missions. This includes the DOE's production of plutonium-238 (Pu-238) and the subsequent processing of the isotope into useable form as a heat source for thermal power to support NASA missions.

The NASA RPS Program structure consists of multiple program office elements focused on RPS Mission support, in addition to system development projects. These projects mature RPS-needed technologies and transition them into flight system designs, ultimately allowing DOE to fuel and deploy RPS for NASA missions.

The projects of the RPS Program include two NASA-led projects leveraging thermoelectric and dynamic energy conversion investments. These projects are coupled with DOE to acquire system design contracts which could lead to availability of a flight system. In addition, the DOE implements activities managing Constant Rate Production for ongoing production of heat source material and subsequent manufacturing into its final flight form. This interagency scope is codified in accordance with a 2016 Memorandum of Understanding and lower-tier agreements.[1,2]

I.A. Acquiring Power Flight Systems

The RPS Program's core purpose is to deliver reliable radioisotope power systems to enable science and exploration missions. To that end, the Program works with DOE to ensure there is fuel available to enable missions, as well as power and heat systems. The Program also works to improve power system capabilities. There are two projects that are developing flight system designs that will produce qualified hardware in preparation for future missions with improved systems.

These projects are at different stages in their maturation cycle: The Dynamic Radioisotope Power Systems (DRPS) Project is a NASA-managed technology development project working towards maturing technologies that could be used in a future flight system design, and the Next Generation Radioisotope Thermoelectric Generator (Next Gen RTG) is a NASA-managed flight design effort to reestablish the ability to produce GPHS-RTGs as closely to the original design as possible.

Accommodating both spaceflight and nuclear systems requirements requires a close relationship between DOE and NASA. The system acquisition and design processes are conducted using DOE Federally Funded Research and Development Centers, to ensure these systems meet all requirements that will allow a future mission to integrate these technologies safely and appropriately. The RPS Program's projects are employing the Idaho National Laboratory (INL) contractor as the agent to acquire flight

systems that can be fueled and launched to fulfill future mission needs.

I.A.1. Power Flight System Builds

For systems such as the Multi-Mission Radioisotope Thermoelectric Generator (MMRTG), supporting activities typically involve procuring, building, fueling, and integrating the as-designed system for the mission. The Program ensures these systems are available. For instance, after the launch of flight unit 1 (F-1) for the Mars Science Lab mission, the Program, working with the DOE, procured F-2 and F-3 to reduce mission risks. In addition, the Program worked with DOE to establish Constant Rate Production and compliance with National Security Presidential Memorandum (NSPM)-20. These activities, in addition to delivering and successfully integrating F-2 for the Mars 2020 Mission resulted in RPS mission cost and schedule savings, and a high performance power system that exceeded the minimum power performance requirement. The Mars 2020 rover Perseverance has been exploring the Jezero Crater on Mars for over 2 years and has dropped the first sample depots for future return to Earth by the future Mars Sample Return Mission. The MMRTG unit F-3 is built and in storage, awaiting future mission utilization.

The next application of the MMRTG will be for the New Frontiers 4 Dragonfly mission, which will visit Titan, the largest moon of Saturn. Dragonfly is scheduled to launch in 2027 with arrival at Titan by 2034. Dragonfly is a unique eight-bladed rotorcraft that will explore the richly organic moon of Titan to advance the knowledge for the building blocks of life. The heat and electrical power provided by a single MMRTG (F-4) will enable Dragonfly to conduct this campaign. The fabrication of the MMRTG is well underway and on schedule.

I.A.2. Light Weight Radioisotope Heater Unit

For missions requiring solely heat and not power, Light Weight Radioisotope Heater Units (LWRHUs) are available. These provide approximately 1 W of heat and are used to keep spacecraft components and systems warm so that the equipment can survive the cold environment of space. An adequate supply of LWRHUs is also available for potential Dragonfly mission use .

I.A.3. Next Generation RTG Development

To meet future mission demand, the RPS Program has been working with the DOE to initiate a project to reestablish the General Purpose Heat Source-RTG (GPHS-RTG). This system has been used with great success by missions such as Galileo to Jupiter, Cassini to Saturn, and New Horizons to Pluto and the Kuiper Belt.

Known as the Next Generation RTG, this power system builds upon the successful technical heritage of the GPHS-RTG. The Next Gen RTG is designed for operation in the vacuum of space and will employ the heritage Silicon Germanium (SiGe) unicouple design as the thermoelectric energy conversion technology. This unicouple was successfully used in the Multi Hundred Watt-RTGs (MHW-RTGs) that have operated for more than 45 years aboard Voyager 1 and 2, as well as in the GPHS-RTGs flown on Galileo, Ulysses, Cassini, and New Horizons.

The Next Gen RTG project will deliver two variants of these RTGs. The first variant, known as Mod 0 ("mod zero"), is an in-depth refurbishment of a single legacy GPHS-RTG flight unit 5 (F-5) depicted in Fig. 1. This effort leverages legacy "off-the-shelf" hardware to provide a flight unit ready for mission use prior to the delivery of new Next Gen RTG flight hardware (Mod 1). The Mod 0 unit may utilize Step-1 GPHS modules depending on mission launch and flight characteristics. A single Mod-0 unit will be delivered in advance of the Mod 1 system.

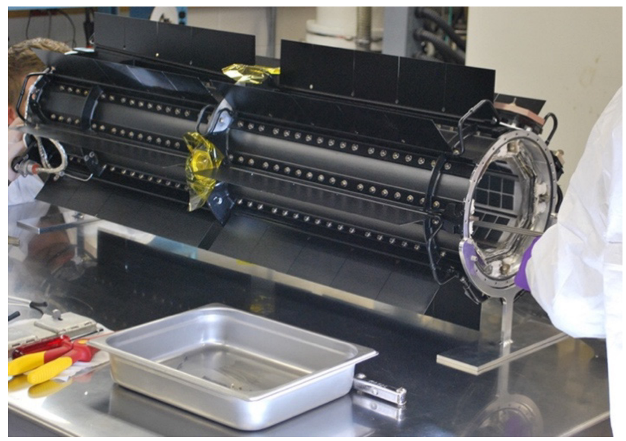

Fig. 1. Next Gen RTG Mod-0 Inspection. Credits: DOE/INL

The Next Gen RTG Mod 1 will be designed as a build-to-print reproduction of the GPHS-RTG with minimal modifications required for the use of Step-2 GPHS modules, and replacement of any obsolete components. The Next Gen Mod 1 system will require the re-establishment of a new SiGe unicouple production line. In addition, the manufacturing capability to produce the Multi-Layer Insulation (MLI) package together with the overall system assembly will need to be re-established.

By building upon the historic design heritage and demonstrated performance of the GPHS-RTG, the Next Gen RTG will continue to provide NASA with the power to explore for decades more to come.

I.A.4. Dynamic Radioisotope Power System Development

The DRPS project has continued to make progress in technology maturation of a dynamic RPS design. The greater conversion efficiency of DRPS enables missions to operate in both vacuum and atmospheric environments with a major benefit of using less heat source material to produce needed power. This also reduces the associated

waste heat and emitted radiation. Reduced waste heat could be important for missions to the permanently shadowed regions of the Moon, asteroids, comets, and icy worlds where volatiles could be affected. Lower levels of emitted radiation could be important for robotic life detection missions or for powering human-class rovers where astronauts perform operations in frequent, close proximity to the RPS.

The DRPS project, in conjunction with INL, has successfully passed an independent review board technology review gate, and has also successfully conducted a review of the first phase of the system design with the INL System Integration Contractor Aerojet Rocketdyne. The current system design is depicted in Fig. 2.

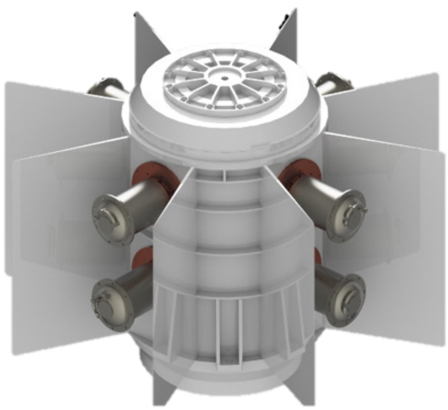

Fig. 2. DRPS generator design.

I.B. Constant Rate Production (CRP)

The management of production capabilities and nuclear facilities requires specialized processes, skills, and security which are well understood and provided by the DOE. In 2017, DOE and NASA agreed to transition the delivery of RPS from a mission-driven approach to a CRP approach. Under the CRP program, components, materials, facilities, and expertise across the plutonium production supply chain are managed to produce a steady flow of heat sources, instead of individual mission needs. The outcome of CRP is an underlying base of shelf-ready, flight-quality components readily available for NASA mission use. This strategy helps reduce the overall mission schedule and risks. The goals of CRP are to produce an average of 1.5 kg of heat source Pu-238 oxide annually by 2026 and to manufacture an average of 10–15 fuel clads (FCs) a year.

Since the demonstrated success of the CRP program for the Mars 2020 mission, the focus of CRP is on scaling up production; optimizing processes; and maintaining, modernizing, and replacing equipment and infrastructure.

Additionally, the DOE and its national laboratories have developed a plan to re-establish LWRHU production capabilities and to manufacture and fuel new flight-certified units. NASA has agreed to proceed with the effort, with the production quantities and the associated timeframe to be established in alignment with mission requirements.

I.C. National Environmental Policy Act (NEPA) and Launch Authorization

The Program is responsible for facilitating successful NEPA and launch authorization compliance for missions and programmatic policy infrastructure. The RPS Program follows a documented process for NEPA and launch authorization management which involves working with NASA, DOE, and other organizations. This highly involved process to achieve nuclear launch authorization ensures nuclear safety and environmental protection, while optimizing available data and resources.

As with the hardware support provided to missions, the RPS Program seeks to ensure the NEPA and launch authorization processes are as efficient as possible, without sacrificing safety. There are several parallel efforts underway to streamline and improve both the NEPA and nuclear launch authorization processes.[3] These include:

- Revisions to the Center of Environmental Quality (CE-Q) NASA NEPA Rule to maximize NASA's administrative efficiency in ensuring appropriate NEPA compliance[4]
- Environmental Management Division (EMD) publication of a Programmatic Environmental Assessment (PEA) to provide NEPA coverage for future RHU-only missions[5]
- EMD, RPS Program and DOE development of a GPHS System PEA
- DOE development of a Documented Safety Analysis (DSA) for both LWRHU and GPHS modules, and
- OSMA rewrite of the NASA Nuclear Flight Safety NPR and similar internal and external policy documents
- OSMA revisions to the Interagency Nuclear Standing Review Board (INSRB) Playbook to provide more guidance and clarity in the process

II. OUTLOOK

The RPS Program and the DOE are continually looking to ensure mission success while reducing cost and improving technology capabilities. The interagency activities to develop and utilize RPS will continue to enable space exploration not possible with conventional solar power. The current decadal, *Origins, Worlds, and Life, A Decadal Strategy for Planetary Science and Astrobiology 2023 – 2032*[6], identifies the most important questions facing planetary science and missions. Many of the missions needed to answer these questions are enabled or significantly enhanced with RPS. Missions conducted over the past using RPS have conducted extended operations of four or more times than possible using solar power.[7] It is important to provide these missions with systems that are available, affordable, and reliable.

The current NASA investments made across agency boundaries ensure fuel inventory is available and ready for NASA mission use; RPS Program's operational processes improvement activities drive mission savings; the development and production of flight systems continue giving missions the power to explore. These investments enable the continued use of RPS for decades to come.

III. CONCLUSIONS

The NASA RPS Program was created to ensure the availability of RPS for the exploration of the solar system in environments where conventional solar or chemical power generation is impractical or impossible. The strong NASA and DOE partnership on the RPS Program has yielded significant achievements: establishing continuous production of heat-source Pu-238, the successful MMRTG-powered Perseverance Mission, and the streamlining of the NEPA and launch approval processes. Continuing to utilize the strengths of each Agency, NASA is leading technology maturation and flight systems developments. DOE continues to manage the nuclear system development and deployment and constant rate production processes enable exploration for the NASA mission community.

Radioisotope power systems developed through this partnership ensure future missions will have access to the most extreme environments in the solar system, probing the sunless depths of lunar craters, flying across the surface of Saturn's moon Titan to search for the building block of life, or touring the rings and moons of the ice giant planet Uranus. With this vital technological capability, the possibilities for exploration and discovery are limited only by our imaginations.

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